

Doppler Tracking System Mathematical Model

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The mathematical model that can be used to calculate the expected Deep Space Instrumentation Facility (DSIF) doppler tracking system phase noise σ_M is given by

$$\sigma_M = \sqrt{\sigma_R^2 + \sigma_A^2}$$

The rms phase noise σ_R is due to the receiver input noise and is a function of the received signal strength. The strong signal phase noise σ_A is characteristic of station configuration and for practical purposes is independent of signal strength. The value of σ_A is determined experimentally. The test results confirm the validity of the model.

I. Introduction

A model of the DSIF doppler tracking system has been developed. The purpose of the model is to predict the doppler system phase noise σ_M , which is measured with the Doppler System test. A block diagram of the system is shown in Fig. 1.

The results of this work show that the system rms phase noise σ_M can be accurately modeled by

$$\sigma_M = \sqrt{\sigma_R^2 + \sigma_A^2} \quad (1)$$

where σ_R is the rms loop phase noise due to received noise, and σ_A is the strong signal phase noise, which is dependent on station configuration.

II. Rms Loop Phase Noise

As given by Tausworthe (Ref. 1, p. 82)

$$\sigma_R^2 = \frac{\Gamma}{m\gamma^2} \left[\frac{1 + \left(\frac{a}{a_0}\right)\gamma}{1 + r_0} r_0 \right] \quad (2)$$

In Fig. 2, rms loop phase noise σ_R is plotted as a function of m , the signal level in dB above threshold, for $\omega_{L0} = 12, 48$, and 152 Hz (ω_{L0} is the VCO loop filter bandwidth at threshold). As shown by Burt (Ref. 2), measured results agree closely with the theoretical calculation for $\sigma_R > 10$ deg. With increasing signal level, σ_R falls below the strong signal phase jitter σ_A (Ref. 3).

III. Strong Signal Phase Noise

At high S/N ratio, $m > 40$ dB, the receiver phase noise σ_R is small compared to other sources of noise in the system. The experimental results indicate that the total system noise can be obtained by taking the square root of the sum of the squares of the separate sources. Because the receiver VCO loop bandwidth varies with signal

strength, the strong signal phase noise also varies with bandwidth; however, in so far as the accuracy of Eq. (1) is concerned, the strong signal jitter can be assumed constant.

For the system doppler test there are four station configurations:

- (1) Test translator (closed-loop test).
- (2) Zero-delay device (closed-loop test).
- (3) Test transmitter with common frequency standard.
- (4) Test transmitter with separate frequency standard.

The station configuration can be altered by the selection of one of the three bandwidths.

Thus, the strong signal phase noise can be identified as

$$\sigma_A = \sigma_{A_{jk}}$$

where j indicates the system configuration and k indicates the VCO loop filter bandwidth used.

Almost every block in the diagram of Fig. 1 contributes to the system phase noise. An important use of the doppler tracking system model will be to permit comparison with measured data in isolating faulty component parts.

The identifiable sources of strong signal noise are given in Table 1.

IV. Test Results

Most of the testing to date has been done with the receiver test, which measures the doppler phase noise at the output of the 12.5-MHz phase detector (Point 1 in Fig. 1).

The relationship between the noise as measured by the receiver test, σ'_M , and the noise as measured by the system test, σ_M , is

$$\sigma_M = \sqrt{\sigma'_M + 1^2 + (3.6)^2 + 1.08} = \sqrt{\sigma'_M + 15.04}$$

The value of σ_A for the test translator configuration with $\omega_{L0} = 12$ Hz was measured and found to be 4.0 deg. The predicted values of

$$\sigma_M = \sqrt{\sigma_k^2 + \sigma_A^2}$$

are plotted in Fig. 5. Also plotted are the predicted value of

$$\sigma'_M = \sqrt{\sigma_k^2 + \sigma_A^2 - 15.04}$$

The measured values of the phase noise as a function of received signal strength above design threshold are also plotted and are seen to agree well with the predicted value of σ'_M .

References

1. Tausworthe, R. C., *Theory and Practical Design of Phase-Locked Receivers, Volume I*, Technical Report 32-819, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1966.
2. Burt, R. W., "DSIF Systems Test Analysis and Verification," in *The Deep Space Network*, Space Programs Summary 37-56, Vol. II, pp. 131-134. Jet Propulsion Laboratory, Pasadena, Calif., Mar. 31, 1969.
3. Bunce, R. C., "Effect of VCO Noise on Phase-Lock Receiver Performance," in *The Deep Space Network*, Space Programs Summary 37-61, Vol. II, pp. 115-120. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 31, 1970.

Table 1. Sources of strong signal noise

Contributor	Nominal phase noise deviation, deg	Comments
Rubidium standard, synthesizer, multipliers, and VCO	1.0	From the frequency standard curve in Fig. 3; the minimum noise from other sources is 4.3 deg. Due to cancellation of correlated noise at the output of multiplier B, the effective noise is 1 deg.
Doppler extractor	3.6	As measured
TDH: Digital noise Quantization error	1.0 1.04	As measured For values of $\sigma_M > 2.2$ this error is a constant. For $\sigma_M > 2.2$ the error is a function of the mean values of the phase as shown in Fig. 4.

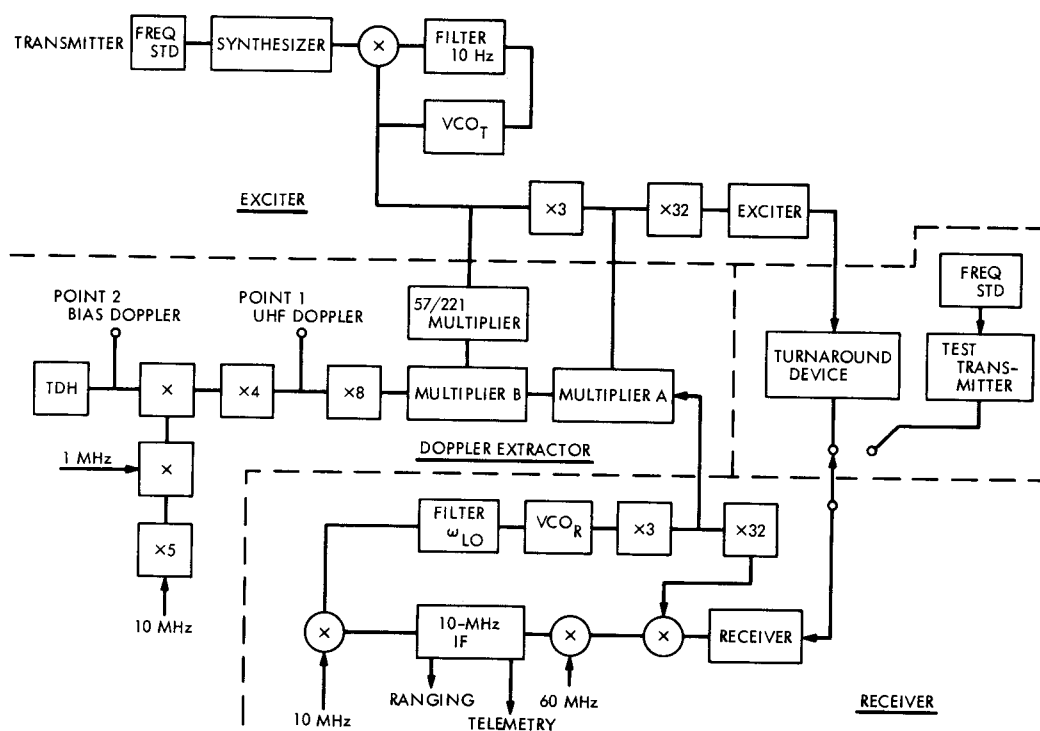


Fig. 1. Block diagram of doppler system

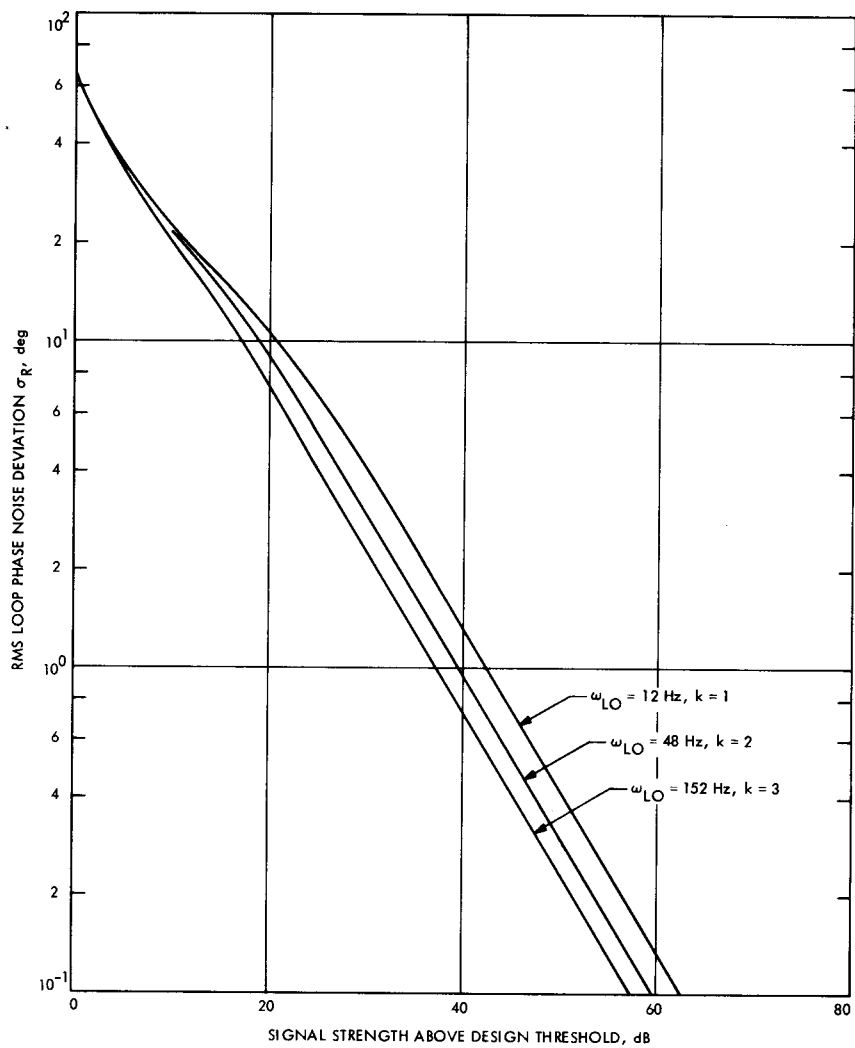


Fig. 2. Rms loop phase noise referenced to S-band vs signal strength

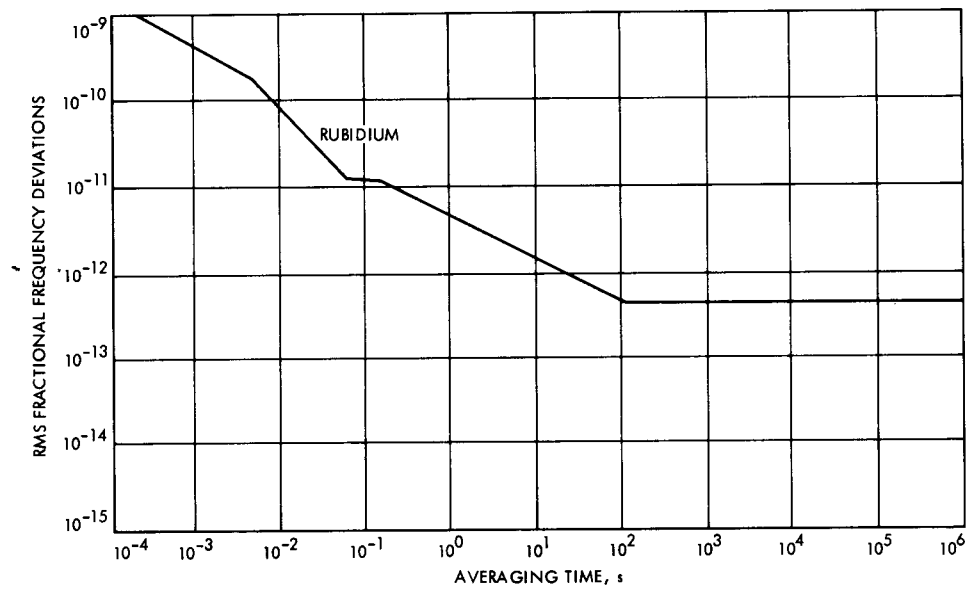


Fig. 3. Rubidium standard fractional frequency deviation

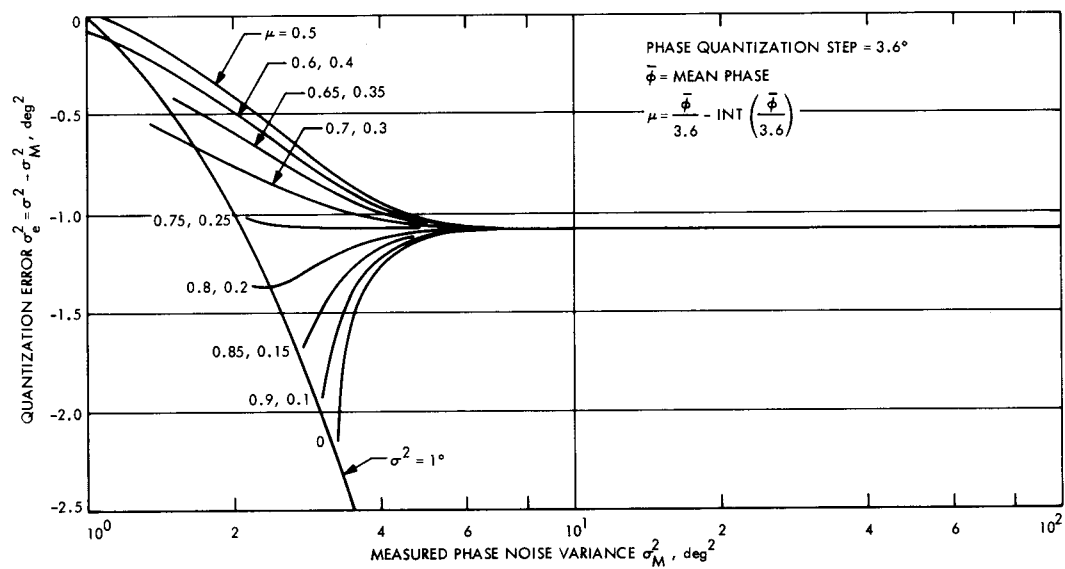


Fig. 4. Quantization error

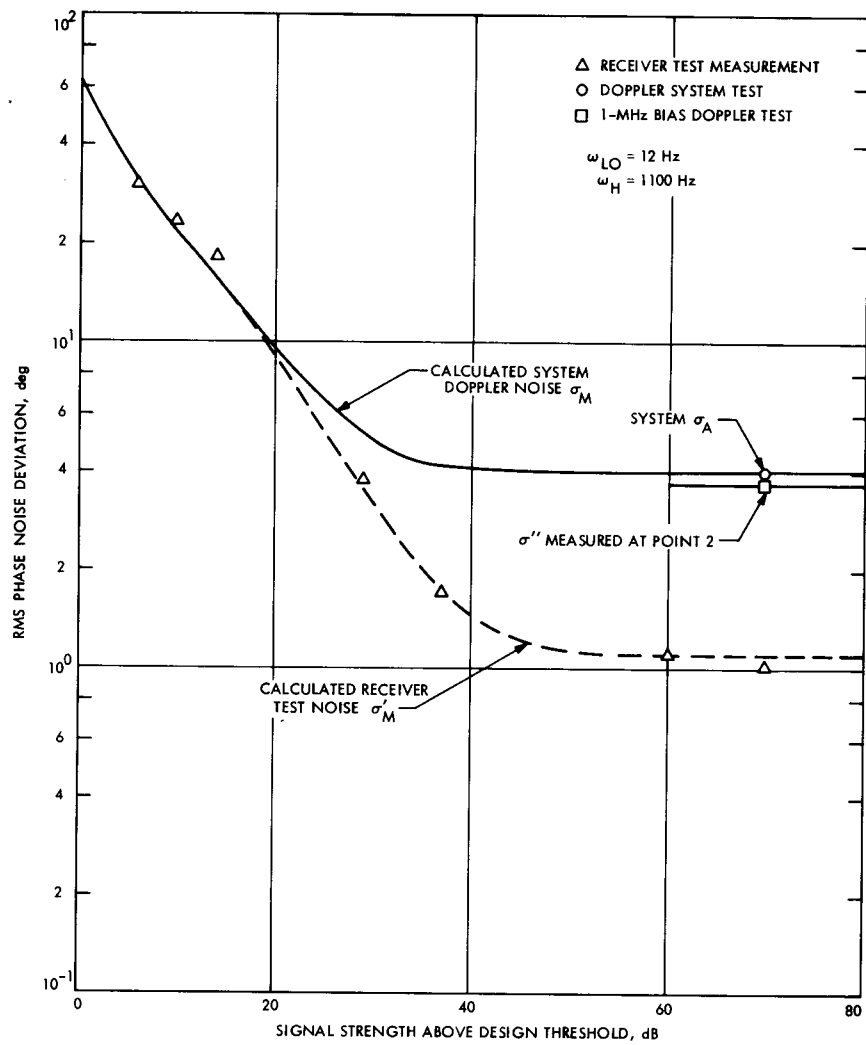


Fig. 5. System model